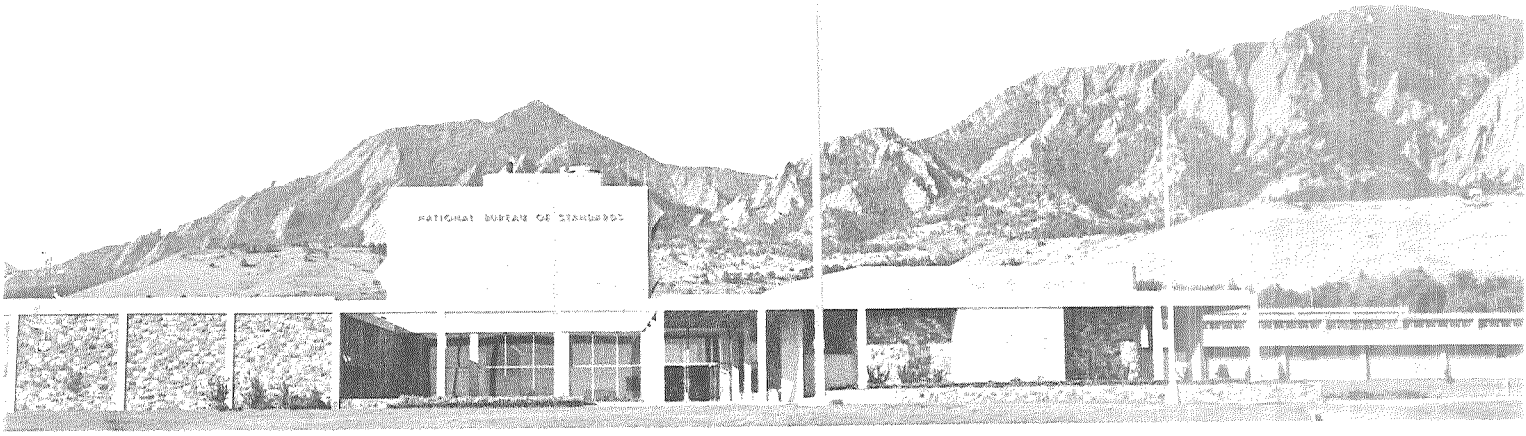

NBS REPORT
9797

FORTY-SECOND PROGRESS REPORT

to

National Aeronautics and Space Administration

on

Cryogenic Research and Development

Period Ending June 30, 1971

U. S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS
Institute for Basic Standards
Boulder, Colorado 80302

NATIONAL BUREAU OF STANDARDS

The National Bureau of Standards[1] was established by an act of Congress March 3, 1901. The Bureau's overall goal is to strengthen and advance the Nation's science and technology and facilitate their effective application for public benefit. To this end, the Bureau conducts research and provides: (1) a basis for the Nation's physical measurement system, (2) scientific and technological services for industry and government, (3) a technical basis for equity in trade, and (4) technical services to promote public safety. The Bureau consists of the Institute for Basic Standards, the Institute for Materials Research, the Institute for Applied Technology, the Center for Computer Sciences and Technology, and the Office for Information Programs.

THE INSTITUTE FOR BASIC STANDARDS provides the central basis within the United States of a complete and consistent system of physical measurement; coordinates that system with measurement systems of other nations; and furnishes essential services leading to accurate and uniform physical measurements throughout the Nation's scientific community, industry, and commerce. The Institute consists of a Center for Radiation Research, an Office of Measurement Services and the following divisions:

Applied Mathematics—Electricity—Heat—Mechanics—Optical Physics—Linac Radiation[2]—Nuclear Radiation[2]—Applied Radiation[2]—Quantum Electronics[3]—Electromagnetics[3]—Time and Frequency[3]—Laboratory Astrophysics[3]—Cryogenics[3].

THE INSTITUTE FOR MATERIALS RESEARCH conducts materials research leading to improved methods of measurement, standards, and data on the properties of well-characterized materials needed by industry, commerce, educational institutions, and Government; provides advisory and research services to other Government agencies; and develops, produces, and distributes standard reference materials. The Institute consists of the Office of Standard Reference Materials and the following divisions:

Analytical Chemistry—Polymers—Metallurgy—Inorganic Materials—Reactor Radiation—Physical Chemistry.

THE INSTITUTE FOR APPLIED TECHNOLOGY provides technical services to promote the use of available technology and to facilitate technological innovation in industry and Government; cooperates with public and private organizations leading to the development of technological standards (including mandatory safety standards), codes and methods of test; and provides technical advice and services to Government agencies upon request. The Institute also monitors NBS engineering standards activities and provides liaison between NBS and national and international engineering standards bodies. The Institute consists of the following technical divisions and offices:

Engineering Standards Services—Weights and Measures—Flammable Fabrics—Invention and Innovation—Vehicle Systems Research—Product Evaluation Technology—Building Research—Electronic Technology—Technical Analysis—Measurement Engineering.

THE CENTER FOR COMPUTER SCIENCES AND TECHNOLOGY conducts research and provides technical services designed to aid Government agencies in improving cost effectiveness in the conduct of their programs through the selection, acquisition, and effective utilization of automatic data processing equipment; and serves as the principal focus within the executive branch for the development of Federal standards for automatic data processing equipment, techniques, and computer languages. The Center consists of the following offices and divisions:

Information Processing Standards—Computer Information—Computer Services—Systems Development—Information Processing Technology.

THE OFFICE FOR INFORMATION PROGRAMS promotes optimum dissemination and accessibility of scientific information generated within NBS and other agencies of the Federal Government; promotes the development of the National Standard Reference Data System and a system of information analysis centers dealing with the broader aspects of the National Measurement System; provides appropriate services to ensure that the NBS staff has optimum accessibility to the scientific information of the world, and directs the public information activities of the Bureau. The Office consists of the following organizational units:

Office of Standard Reference Data—Office of Technical Information and Publications—Library—Office of Public Information—Office of International Relations.

---

[1] Headquarters and Laboratories at Gaithersburg, Maryland, unless otherwise noted; mailing address Washington, D.C. 20234.
[2] Part of the Center for Radiation Research.
[3] Located at Boulder, Colorado 80302.

NATIONAL BUREAU OF STANDARDS REPORT

NBS PROJECT
27500-2750400
27503-2750430
27503-2750438
27505-2750451
27505-2750550
27506-2750460

June 30, 1971

NBS REPORT
9797

FORTY-SECOND PROGRESS REPORT

to

National Aeronautics and Space Administration

on

Cryogenic Research and Development

for

Period Ending June 30, 1971

Cryogenics Division
Institute for Basic Standards
National Bureau of Standards
Boulder, Colorado

U.S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

TABLE OF CONTENTS

Item Number	TASK ↓ / PHASE OF TASK →	Active Coord. with Lewis, MSFC, LASL	Not Started	Preliminary Planning	Apparatus Designing	Apparatus Construction	Data Taking	Data Analysis	Report Composition	Report in Press	Est. Completion Date	For Latest Report or Publication on This Task See: Quart. Report #	page	item #	Provisional (P) or Final (F)	Task Completed
1.	Cryogenic Properties of Solids										*					
1.1	Thermal Conductivity									x	11/1/71					
1.2	Electrical Resistivity								x							
2.	Slush Hydrogen										1/1/72					
2.1	Heat Transfer			x												
2.2	Hydrocarbon Suspension				x		x	x			1/1/72					
3.	Slush Hydrogen Instrumentation					x	x	x								
4.	Consultation & Advisory Services										*					
4.1	NERVA Program															

* Continuing effort

1. Cryogenic Properties of Solids

1.1 Thermal Conductivity of Solids

1.1.1 General Comments

The objectives of this program are (1) to measure the thermal conductivities of several standard reference materials, (2) to study Lorenz ratio of several classes of materials, and (3) to study the conduction mechanisms in alloys in the temperature range from 4 to 300 K.

Personnel contributing during the reporting period were J. G. Hust and L. L. Sparks.

1.1.2 Program Status

During the current period the Lorenz ratio compilation has been nearly completed. The literature search is complete, references have been received, and data are now being punched on cards for computer analysis. This analysis will be completed during the next reporting period.

Measurements have been completed on both lots of AGARD stainless steel. We have found that hot swaging and reannealing does not alter the thermal conductivity of this steel. Therefore we are proceeding with specimen preparation for distribution by OSRM. The specimen preparation is being done by USBM, Albany, Oregon. An additional 200 pounds of this steel have been ordered from the German supplier. A report will be completed during the next period describing the results of characterization and measurements.

Also, during the next period we will continue to analyze the heat conduction mechanisms of the alloys measured in the past.

1.2 Electrical Resistivity

1.2.1 General Comments

The objectives of this project are to measure the low temperature electrical resistivity of selected alloys needed for cryogenic design and to study their material variability, and to perform precision measurements of resistivity for several high purity metals to improve understanding of the basic electron scattering mechanisms and to improve the reliability of standard reference data.

The material variability program has been completed and is reported. A. F. Clark contributed during this reporting period.

1.2.2 Program Status

Nearly 50 measurements were performed for the material variability program and are reported along with the previous measurements in Tables 1.2.1 - 1.2.5. Analysis of the data has been completed and an article has been written for submission to Cryogenics. A preprint of this article will be appended to the next progress report.

During the next reporting period the measurement of the precision electrical resistivity of aluminum will be initiated.

Table 1.2.1 Low Temperature Electrical Resistivity - Al 2024

VARIABLE			CONDITION	RESISTIVITY μΩm				
Mfg.	Heat	Within Heat		273 K	192.4 K	75.75 K	19.65 K	4.0 K
AS RECEIVED CONDITIONS								
		A23a	Unknown (Prob. 0)	.03267	.02279	.00876	.00610	.00607
		A23b	Unknown (Prob. 0)	.03276	.02275	.00883	.00618	.00610
		A23c	Unknown (Prob. 0)	.03267	.02285	.00891	.00622	.00619
		A23d	Unknown (Prob. 0)	.03256	.02270	.00867	.00598	.00595
	(A23)		(Av of A23a-d)	(.03267)	(.02277)	(.00879)	(.00612)	(.00608)
	A21		Unknown (Prob. 0)	.03259	.02270	.00874	.00607	.00604
	A22		Unknown (Prob. 0)	.03262	.02316	.00919	.00649	.00646
	A24		Unknown (Prob. 0)	.03170	.02227	.00845	.00574	.00572
(A2)			(Av of A21-4)	(.03240)	(.02273)	(.00879)	(.00611)	(.00608)
A1			T4	.05714	.04821	.03537	.03272	.03269
9			T86	.04208	.03234	.01866	.01581	.01578
A3			Unknown (Prob. T4)	SEE BELOW				
HEAT TREATED CONDITIONS								
		A23a	"0"	.03178	.02209	.00792	.00524	.00521
		A23c	"0"	.03324	.02356	.00931	.00658	.00654
	(A23)		(Av A23a and c)	(.03251)	(.02283)	(.00862)	(.00591)	(.00588)
	A21		"0"	.03206	.02238	.00805	.00536	.00533
(A2)			(Av A21 and 23)	(.03229)	(.02261)	(.00834)	(.00564)	(.00561)
9			"0"	.03238	.02246	.00854	.00586	.00583
A1			"0"	.03361	.02398	.00962	.00690	.00687
(Av-0)			(Av of A2, 9, and A1)	(.03276)	(.02302)	(.00883)	(.00613)	(.00610)
9			T4 (After Ann.)	.04353	.03392	.02025	.01745	.01742
A1			T4	.05967	.05098	.03829	.03567	.03564
A21			T4	.06035	.05165	.03897	.03634	.03632
A3			Unknown (Prob. T4)	.05648	.04740	.03461	.03194	.03191
(Av-T4)			(Av of 9, A1, A21, A3)	(.05501)	(.04599)	(.03303)	(.03035)	(.03032)
9			T6	.03996	.03016	.01624	.01341	.01337
A1			T6	.04859	.03930	.02543	.02254	.02251
A21			T6	.04973	.04046	.02655	.02366	.02362
(Av-T6)			(Av of 9, A1, A21-T6)	(.04609)	(.03664)	(.02274)	(.01987)	(.01983)

Table 1.2.2 Low Temperature Electrical Resistivity - Al 5000 series

VARIABLE			CONDITION	RESISTIVITY μΩm				
Mfg.	Heat	Within Heat		273 K	192.4 K	75.75 K	19.65 K	4.0 K
		A53a	Unknown; 5056	.05644	.04697	.03362	.03080	.03076
		A53b	Unknown; 5056	.05649	.04697	.03360	.03077	.03074
		A53c	Unknown; 5056	.05641	.04699	.03357	.03074	.03073
		A53d	Unknown; 5056	.05617	.04679	.03342	.03060	.03057
	(A53)		(Av of 53a-d)	(.05638)	(.04693)	(.03355)	(.03073)	(.03070)
	A51		Unknown; 5056	.05662	.04722	.03370	.03087	.03085
	A52		Unknown; 5056	.05699	.04729	.03455	.03168	.03152
	A54		Unknown; 5056	.05592	.04642	.03285	.03002	.02999
(A5)			(Av of A51-4)	(.05648)	(.04697)	(.03366)	(.03083)	(.03077)
A4			Unknown; 5083	.05591	.04640	.03288	.03007	.03003
7			H 113 across; 5083	.05711	.04741	.03362	.03069	.03065
A6			Unknown; 5456	.05918	.04946	.03556	.03264	.03261
(Av)			(Av of A4-6, and 7)	(.05717)	(.04756)	(.03393)	(.03106)	(.03102)
		7	Annealed; 5083	.05658	.04694	.03319	.03032	.03030
		8	H 113 with; 5083	.05683	.04715	.03344	.03054	.03052

Table 1.2.3 Low Temperature Electrical Resistivity - Inconel 718

VARIABLE			CONDITION	RESISTIVITY μΩm				
Mfg.	Heat	Within Heat		273 K	192.4 K	75.75 K	19.65 K	4.0 K
ANNEALED								
		Ila	Hot Rolled Annealed	1.2585	1.2382	1.2085	1.2035	1.2098
		Ilb	Hot Rolled Annealed	1.2579	1.2376	1.2082	1.2032	1.2095
		Ilc	Hot Rolled Annealed	1.2548	1.2344	1.2048	1.1996	1.2058
	(Il)		(Av of Ila, b, c)	(1.2571)	(1.2367)	(1.2072)	(1.2021)	(1.2084)
	I2		Hot Rolled Hot Rolled	1.2623	1.2421	1.2157	1.2115	1.2178
	I3		Hot Rolled Annealed	1.2429	1.2257	1.2020	1.1993	1.2056
	I4		Hot Rolled Annealed	1.2438	1.2263	1.2015	1.1977	1.2038
	22		Ann. (After Aging)	1.2553	1.2376	1.2128	1.2104	1.2173
	24		Ann. (After Aging)	1.2254	1.2137	1.1854	1.1825	1.1884
	(Av)		(Av of Il-24)	(1.2478)	(1.2304)	(1.2041)	(1.2006)	(1.2069)
AGED								
		Ila	Aged	1.0929	1.0644	1.0193	1.0100	1.0137
		Ilb	Aged	1.0891	1.0606	1.0156	1.0064	1.0101
		Ilc	Aged	1.0987	1.0703	1.0263	1.0170	1.0208
	(Il)		(Av of Ila, b, c)	(1.0936)	(1.0651)	(1.0204)	(1.0111)	(1.0149)
	I2		Aged	1.1582	1.1324	1.0922	1.0839	1.0881
	I3		Aged	1.1677	1.1423	1.1041	1.0965	1.1008
	I4		Aged	1.1289	1.1014	1.0592	1.0502	1.0539
	22		Aged by Mfg.	1.1449	1.1205	1.0839	1.0775	1.0815
	24		Aged by Mfg.	1.0655	1.0357	0.9925	0.9839	0.9882
	(Av)		(Av of Il-24)	(1.1265)	(1.0996)	(1.0587)	(1.0505)	(1.0547)

Table 1.2.4 Low Temperature Electrical Resistivity - A286 Stainless Steel

VARIABLE			CONDITION	RESISTIVITY μΩm				
Mfg.	Heat	Within Heat		273 K	192.4 K	75.75 K	19.65 K	4.0 K
ANNEALED								
		S4a	H. R. Redraw	.9294	.8753	.7927	.7695	.7701
		S4b	H. R. Redraw	.9298	.8766	.7934	.7704	.7711
		S4c	H. R. Redraw	.9298	.8765	.7938	.7709	.7715
		S4d	H. R. Redraw	.9298	.8759	.7924	.7693	.7700
(S4)			(Av of S4a-d)	(.9297)	(.8761)	(.7931)	(.7700)	(.7707)
	S7a		Solution Annealed	.9365	.8839	.7989	.7745	.7751
	S7b		Solution Annealed	.9371	.8849	.8008	.7758	.7761
	S7c		Solution Annealed	.9466	.8945	.8132	.7907	.7914
	S7d		Solution Annealed	.9383	.8854	.8015	.7774	.7778
(S7)			(Av of S7a-d)	(.9396)	(.8872)	(.8036)	(.7796)	(.7801)
S1			Annealed (After Aging)	.9251	.8707	.7835	.7604	.7615
S2			Solu. Ann. C.D. 15%	.9357	.8823	.7950	.7745	.7752
S3			Annealed (After Aging)	.9474	.8945	.8097	.7868	.7878
(Av Ann.)			(Av of S1-4, and S7)	(.9355)	(.8822)	(.7970)	(.7743)	(.7751)
		S4b	Re-Annealed	.9281	.8740	.7883	.7661	.7670
		S4c	Re-Annealed	.9267	.8728	.7873	.7650	.7661
	S7a		Re-Annealed	.9356	.8823	.7954	.7714	.7721
	S7b		Re-Annealed	.9377	.8841	.7973	.7727	.7733
AGED								
S1			Aged (As Recd)	.8846	.8193	.7169	.6912	.6915
S3			Aged (As Recd)	.9234	.8731	.7937	.7711	.7719
S7a			Aged (After Reann.)	.9032	.8430	.7436	.7154	.7148
(Av Aged)			(Av of S1, S3, S7a)	(.9037)	(.8451)	(.7514)	(.7259)	(.7261)
S3			Aged (After Ann.)	.9094	.8502	.7536	.7268	.7261

Table 1.2.5 Low Temperature Electrical Resistivity - AISI 316 Stainless Steel

VARIABLE			CONDITION	RESISTIVITY μΩm				
Mfg.	Heat	Within Heat		273 K	192.4 K	75.75 K	19.65 K	4.0 K
		S5a	Hot Rolled-Redrawn	0.7679	0.7005	0.5890	0.5573	0.5590
		S5b	Hot Rolled-Redrawn	0.7664	0.6988	0.5869	0.5561	0.5569
		S5c	Hot Rolled-Redrawn	0.7663	0.6992	0.5866	0.5560	0.5568
		S5d	Hot Rolled-Redrawn	0.7661	0.6993	0.5865	0.5559	0.5567
(S5)			(Av of S5a, b, c, d)	(0.7667)	(0.6995)	(0.5873)	(0.5563)	(0.5574)
	S6a		Cold Drawn	0.7574	0.6897	0.5763	0.5465	0.5470
	S6b		Cold Drawn	0.7634	0.6950	0.5832	0.5514	0.5518
	S6c		Cold Drawn	0.7539	0.6861	0.5719	0.5410	0.5416
	S6d		Cold Drawn	0.7564	0.6880	0.5749	0.5439	0.5444
	51		Cold Drawn and Ann.	0.7644	0.6963	0.5856	0.5532	0.5534
	85		Cold Drawn and Ann.	0.7654	0.6967	0.5852	0.5528	0.5531
(S6+)			(Av of S6a-d, 51, 85)	(0.7602)	(0.6920)	(0.5795)	(0.5481)	(0.5486)
86			Cold Drawn and Ann.	0.7757	0.7066	0.5950	0.5626	0.5628
87			Annealed	0.7498	0.6794	0.5663	0.5383	0.5392
88			Cold Drawn and Ann.	0.7184	0.6426	0.5232	0.5015	0.5029
(Av)			(Av of S5, S6+, 86-8)	(0.7542)	(0.6840)	(0.5703)	(0.5414)	(0.5422)

2. Slush Hydrogen Heat Transfer and Hydrocarbon Suspension

2.0 General Comments

Activity on the program during this reporting period has been concerned with completion of the slush mixing study, start up of the experimental apparatus to prepare a hydrocarbon suspension in slush hydrogen, and initiation of the design of the heat transfer experimental apparatus. Personnel contributing to the program were C. Sindt, P. M. McConnell, R. O. Voth, and J. Hord.

2.1 Slush Hydrogen Heat Transfer

The activity on this task has included selection of the basic design for the experimental heat transfer unit. The design selected is similar to that reported by K. J. Coeling and H. Merte, Jr. (1968). This design was selected because it has been used successfully for liquid hydrogen and will therefore provide some correlation data between systems as well as from slush and triple-point liquid to normal boiling liquid. The design heat flux values are estimated to range from the visible boiling threshold to the lowest values measurable on the heater circuit.

2.2 Mixing Slush Hydrogen

The study of mixing requirements and design for slush hydrogen systems has been completed. The study has resulted in selection of the most promising mixer configurations for one-g mixing and for low-g mixing. The completed study will be reported separately during the next quarter and will be titled "Slush Hydrogen Mixing: Preliminary Study".

2.3 Hydrocarbon Suspension in Slush Hydrogen

The apparatus for preparation and study of hydrocarbon suspension in slush hydrogen has been completed and two tests and a checkout run have been made using hydrogen.

2.3.1 Experimental Apparatus and Procedure

The experimental dewar is thermally protected by a liquid hydrogen bath dewar which can be vacuum pumped to triple-point pressure. Triple-point pressure is maintained in the bath dewar with a barostat that controls the pressure within 270 N/m^2 (2 mm Hg). The bath dewar is thermally protected with an open mouth, liquid nitrogen filled dewar. For visual and photographic observation, all of the dewars used are clear glass during the initial experiments. If a stable hydrocarbon suspension is obtained, the bath dewar will be replaced with a strip-silvered dewar to assure long observation periods of the suspension with a minimum of melting of the solid hydrogen in the slush.

The hydrocarbon content of the suspension is determined with a hydrogen flame hydrocarbon analyzer. The suspension sample is taken with a micro-sampler of approximately 1 cm^3 capacity, which can sample at any level in the experimental dewar. The sample which is contained in the fluid sampler is then raised above the liquid hydrogen level and boiled with electrical heaters. The resulting gas is captured in two evacuated chambers. The first chamber is filled to approximately one atmosphere pressure when the hydrogen has gasified. This chamber is then closed and the second evacuated chamber is opened. The second chamber is filled as the remaining hydrogen and the hydrocarbon are heated well above the boiling point of the hydrocarbon. Since the second chamber is over 300 times larger

than the sample volume, 99.7% of the gas mixture remaining after filling the first volume is contained in the second volume. This serves to extract essentially all of the gas sample from the sampler. The two volumes are then mixed with each other resulting in a gas sample typical of the fluid sample trapped in the micro-sampler.

2.3.2 Test of Hydrocarbon Suspensions

Three hydrogen tests have been made in the apparatus. The first test was conducted to check out operation and safety features. The second hydrogen test was conducted with ethane injection into triple-point liquid hydrogen. The injection gas was three volume percent ethane in hydrogen. The injection time was 30 seconds with the pressure at 430 kN/m^2 (50 psig) and the injection was through a 0.33 mm diameter hole. Solid ethane particles which appeared to be as large as 5 mm formed during injection and the particles were of the texture of snow flakes. Hydrogen slush was made after injection. During slush preparation, the mixture was stirred vigorously. After the solids had settled the mixture appeared to contain solid ethane throughout the slush hydrogen. The ethane particles are discernible from solid hydrogen because they are white and the solid hydrogen has the appearance of a wetted translucent particle.

Attempts were made to sample the clear liquid over the settled solids and to sample in the settled solids region. The samples in the settled portion were approximately 700 ppm by weight of ethane; however, the sampler was not functioning properly so this value is suspect. The clear liquid samples contain no detectable ethane.

The mixture of slush and hydrocarbon was stirred on several occasions and the solids always appeared to settle with the ethane well dispersed in the slush. No solid ethane particles were visible in the liquid after settling had occurred. Because of the sampler problem the experiment was terminated without adding more ethane. After the solid hydrogen in the slush had melted the solid ethane appeared to occupy about 1/20 of the liquid volume.

The third experiment was terminated before data were available because of a heater failure.

Since the third experiment, the heaters and the micro-sampler have been modified to increase reliability and to improve the accuracy of the sample.

Future experiments will include more testing with 10% cyclopropane in hydrogen as the injection gases. Experiments where the hydrocarbon is to be added after slush is made will use pure methane as the injection gas initially. The injection gas must be of high hydrocarbon content as the large volume of warm hydrogen gas associated with diluted gas injection will melt a significant portion of the solid hydrogen.

3. Slush Hydrogen Instrumentation

3.0 General Comments

Contributing to the program during this reporting period was R. S. Collier.

3.1 Carbon Film Sensors

Analysis of the thermal oscillations in slush was begun using the heat and mass transport equations. If the viscosity of the fluid and the slush is neglected there are six relevant quantities at each point in the fluid — namely, the three fluid velocity components, $\vec{v}$; the density, ρ; the pressure, P; and the temperature, T. In order to solve for any of these quantities for any point in the fluid as a function of time (the Eulerian point of view), it is necessary to establish six independent relations between the quantities. The conservation of momentum gives three independent relations, the conservation of mass and energy gives two more, and the last relation is obtained from the equation of state which related P, ρ, and T in a state of thermodynamic equilibrium. Since the thermal oscillations are low frequency (approximately 8 Hz) and the thermal amplitudes are small (approximately 0.1 K), we shall assume that the equation of state holds locally even though the system is not in thermal equilibrium.

$$\rho \frac{Dv}{Dt} = - \nabla P \tag{1}$$

where D/Dt is the convective derivative $\partial/\partial t + v \cdot \nabla$. The conservation of mass is expressed as

$$\frac{\partial}{\partial t} \rho + \nabla \cdot \rho v = 0. \tag{2}$$

To a first approximation, the slush can be treated as an incompressible fluid. Under this assumption and considering spherical symmetry of

the pressure and velocity waves about the film sensor, equations (1) and (2) can be integrated in the space variable to give

$$R\frac{d^2R}{dt^2} + \frac{3}{2}\left(\frac{dR}{dt}\right)^2 = \frac{1}{\rho}(P_R - P_\infty) \qquad (3)$$

where R is the radial position of a fluid particle, P_R is the fluid pressure at R, and P_∞ is the ullage pressure. Using some simple approximations relating P_R to R we have found the conditions for which the computer solutions to equation (3) are oscillatory. The next step is to relate these oscillations to the thermal oscillations using the energy equation, the Equation of State, and the boundary conditions giving the heat input. This work is continuing and the full details will be given in a future report.

Work was begun with Metro Physics, Inc., Santa Barbara, California, to transfer our carbon film technology and to obtain a source of carbon films which will be used as slush sensors, thermometers, and fluid phase detectors.

Six deposition runs were made using eight film substrates per run. The first problem was to establish a deposition rate which would be held constant on succeeding runs. The deposition rate had to be slow enough to make stable films, yet high enough to make a 500Å - 1000Å film in a reasonable length of time. (This rate had been previously determined by NBS research to be about 0.5 - 2.0 Å/min.) The rate of thickness was determined by a shielded quartz crystal monitor. The crystal monitor was placed 8 inches from the source and the substrates 24 inches from the source. Using the $1/R^2$ law and figuring the rotation of the substrate, there is a factor of 9π between the rate of the crystal

monitor and the rate at the substrate. We therefore initially kept the rate at the crystal monitor about 60 Å/min for a flat non-rotating substrate. At this rate we were able to deposit 600 Å films in about five hours, which gave sensor resistance of 300 - 1500 Ω at room temperature (the range being dependent on the substrate temperature). At this rate, the rotating substrates had films which were of excellent optical quality, were stable, and reproducible to within 0.1 percent on thermal cycling (more sensitive measurements will be forthcoming). However, the flat substrates at 6 Å/min were all unstable.

The nominal rate of 60 Å/min at the quartz crystal monitor was controlled by the emission current of the electron beam gun which had a tendency to drift and required a correction at intervals of about 10 minutes. The rate then was usually kept between 50 - 70 Å/min, although it would occasionally drop as low as 40 Å/min or get as high as 80 Å/min. An automatic emission current controller would be very helpful here, but may require very sophisticated circuitry as there are time lags of 4 or 5 minutes to changes in emission current.

The next problem was to control the substrate temperature and measure the effect of substrate temperature on the total resistance and sensitivity (as measured by the resistance ratio between room temperature and liquid nitrogen boiling point). The first attempt at reproducibility gave very good results (to within 10 percent in sensitivity and resistance) although the sensitivity seemed to be a little too high. The next two runs were unsuccessful in establishing a definite trend of sensitivity vs. substrate temperature and we began to notice a correlation with respect to substrate position. The final two runs, after eliminating the effect of all other parameters, showed that the relevant parameter seemed to be the warm up time. A

hypothetical reconstruction of events goes as follows: The substrates are mounted axially on beveled rollers about 2 inches in diameter and 2 inches long. Eight rollers fit in a thrust bearing and rotate on a 12-inch diameter circle. The bottom bearing is heavy aluminum (called the track) and the top bearing is heavy aluminum (called the wheel). The rollers roll between the wheel and the track. The wheel is warmed from above by quartz lamps and the track is warmed from below by quartz lamps and the carbon source. However, the rollers are warmed primarily by conduction at the points of contact between the track and wheel. It was necessary to give the rollers a heavy coat of moly-disulfide to prevent sticking, probably making a poor thermal contact. Thus, it may take longer than the 3 or 4 hours which were allowed to come to thermal equilibrium. The temperature of the wheel and track was monitored, but the roller temperatures are difficult to determine. This hypothesis seems to explain everything that we observed, including the location correlation and the first attempt at reproducibility which had very nearly the same warm up time.

It seemed reasonable to stop the calibration runs temporarily and do some separate experiments to instrument one or two of the rollers in a static test to determine the warm up time. Metro Physics will do this in the next week or two and will also build a controller which will allow long warm up times, say, over the weekend. If this experiment is successful, it would be desirable to do three or four more calibration runs where more information is known about the actual substrate temperature.

4. Consultation and Advisory Services

4.0 General Comments

Contributing personnel were A. F. Schmidt and H. M. Roder.

4.1 NERVA Program

During the reporting period, various organizations were provided information on hydrogen properties data: (1) NBS Reports 9288 and 9711 were furnished S. Wilkes (Martin-Denver); (2) NBS Report 9288 and a hydrogen properties TAB deck were sent to R. F. Hausman (Lockheed-Sunnyvale); (3) NBS Report 9711 was requested by Mrs. M. Lura (Sandia Corporation); (4) a high temperature hydrogen generating function deck was sent to R. A. Silver (Edwards Air Force Base, Calif.); (5) para and equilibrium hydrogen properties diagrams were discussed with C. L. Carwile (SNSO-C); (6) references for high temperature hydrogen properties were given to S. Manatt (AiResearch Corp.). Also, helium properties charts and tables were provided SNSO-C, and discussions on several topics were held with SNSO-W.

The NERVA Engine Design Status Review Meeting was attended May 11-13 at Aerojet Nuclear Systems Company, Sacramento, California. On June 13-14, meetings were held in Boulder with Dr. Landon Nichols concerning both present and proposed work under NASA (SNSO-C) Contract R-45.

NBS TECHNICAL PUBLICATIONS

PERIODICALS

JOURNAL OF RESEARCH reports National Bureau of Standards research and development in physics, mathematics, chemistry, and engineering. Comprehensive scientific papers give complete details of the work, including laboratory data, experimental procedures, and theoretical and mathematical analyses. Illustrated with photographs, drawings, and charts.

Published in three sections, available separately:

• Physics and Chemistry

Papers of interest primarily to scientists working in these fields. This section covers a broad range of physical and chemical research, with major emphasis on standards of physical measurement, fundamental constants, and properties of matter. Issued six times a year. Annual subscription: Domestic, $9.50; foreign, $11.75*.

• Mathematical Sciences

Studies and compilations designed mainly for the mathematician and theoretical physicist. Topics in mathematical statistics, theory of experiment design, numerical analysis, theoretical physics and chemistry, logical design and programming of computers and computer systems. Short numerical tables. Issued quarterly. Annual subscription: Domestic, $5.00; foreign, $6.25*.

• Engineering and Instrumentation

Reporting results of interest chiefly to the engineer and the applied scientist. This section includes many of the new developments in instrumentation resulting from the Bureau's work in physical measurement, data processing, and development of test methods. It will also cover some of the work in acoustics, applied mechanics, building research, and cryogenic engineering. Issued quarterly. Annual subscription: Domestic, $5.00; foreign, $6.25*.

TECHNICAL NEWS BULLETIN

The best single source of information concerning the Bureau's research, developmental, cooperative and publication activities, this monthly publication is designed for the industry-oriented individual whose daily work involves intimate contact with science and technology—*for engineers, chemists, physicists, research managers, product-development managers, and company executives.* Annual subscription: Domestic, $3.00; foreign, $4.00*.

*** Difference in price is due to extra cost of foreign mailing.**

NONPERIODICALS

Applied Mathematics Series. Mathematical tables, manuals, and studies.

Building Science Series. Research results, test methods, and performance criteria of building materials, components, systems, and structures.

Handbooks. Recommended codes of engineering and industrial practice (including safety codes) developed in cooperation with interested industries, professional organizations, and regulatory bodies.

Special Publications. Proceedings of NBS conferences, bibliographies, annual reports, wall charts, pamphlets, etc.

Monographs. Major contributions to the technical literature on various subjects related to the Bureau's scientific and technical activities.

National Standard Reference Data Series. NSRDS provides quantitative data on the physical and chemical properties of materials, compiled from the world's literature and critically evaluated.

Product Standards. Provide requirements for sizes, types, quality and methods for testing various industrial products. These standards are developed cooperatively with interested Government and industry groups and provide the basis for common understanding of product characteristics for both buyers and sellers. Their use is voluntary.

Technical Notes. This series consists of communications and reports (covering both other agency and NBS-sponsored work) of limited or transitory interest.

Federal Information Processing Standards Publications. This series is the official publication within the Federal Government for information on standards adopted and promulgated under the Public Law 89–306, and Bureau of the Budget Circular A–86 entitled, Standardization of Data Elements and Codes in Data Systems.

Consumer Information Series. Practical information, based on NBS research and experience, covering areas of interest to the consumer. Easily understandable language and illustrations provide useful background knowledge for shopping in today's technological marketplace.

NBS Special Publication 305, Supplement 1, Publications of the NBS, 1968-1969. When ordering, include Catalog No. C13.10:305. Price **$4.50;** foreign, $5.75.

Order NBS publications from: Superintendent of Documents
Government Printing Office
Washington, D.C. 20402